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Sagittal spinal alignment measurements and evaluation: Historical perspective

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ABSTRACT

Spinal alignment analysis play an important role in evaluating patients and planning surgical corrections for adult spinal deformity. The history of these parameters is relatively short with the first parameter, the Cobb angle, introduced in 1948 as part of an effort to improve scoliosis evaluation. New developments in the field were limited for nearly 30 years before better imaging technology encouraged new theories and later data about spinal alignment and the relationship between the spine and pelvis. These efforts would ultimately contribute to the creation of foundational spinal alignment parameters, including pelvic incidence, pelvic tilt, and sacral slope. By the 1990s, spinal alignment had become a sustained area of investigation for spinal surgeons and researchers. Novel alignment parameters have since been introduced as our knowledge has evolved and has allowed for valuable research that demonstrates the clinical and surgical value of alignment measurement. This manuscript will explore the history of spinal alignment analysis over the decades.

Introduction

First performed in 1909, spinal fusion has become one of the most commonly performed surgeries both in the United States and internationally [1]. The incidence of spinal fusion surgeries has increased dramatically over the last several decades, with approximately 32,700 lumbar surgeries in 1990 to now over 1.6 million spinal fusion procedures annually and with an associated cost of nearly $30 billion dollars per year in the US alone [2,3]. Given the increasing age of the population, the incidence of spinal fusion surgery is likely to continue to increase, as is the associated cost. Despite widespread utilization of spinal fusion, high failure rates due to malalignment continue, thus optimizing spinal alignment has all become increasingly important.

Much like the incidence of spinal fusion surgeries, the number of publications related to spinal alignment has grown dramatically over the last several decades. The first article to specifically examine at spinal alignment was published by the Aerospace Medical Division of the US Air Force in 1969 and looked at variations of spinal alignment in egress systems (Fig. 1) [4]. Interest in spinal alignment was minimal with only a few publications per year until there started to be a growing number of publications in the 1990s. Although this is not a formal systematic review but in screening PubMed, in 2023, there were 651 publications related to spinal alignment included, and 304 have already been published in 2024.

Many of the early investigations examine applications of the Cobb angle in the context of scoliosic curves [5]. Several groundbreaking theories, however, encouraged researchers to look beyond the spine which ultimately led to the creation of several new measures of spinal alignment. Arguably one the most important of these initial theories was Jean Dubousset's declaration that "The entire pelvis is a vertebra" in 1972 (Fig. 2). Dubousset also introduced the "cone of economy" to describe the relative movements that occur throughout the body to maintain an upright position as efficiently as possible [6]. These hypothesis, as well as the creation of new spinopelvic parameters was likely motivated by the introduction of full spine (36-inch) x-rays that included the hips and pelvis in France in the 1970s [7].

Despite the important role spinal alignment measurements have played in understanding spine biomechanics and improving surgical

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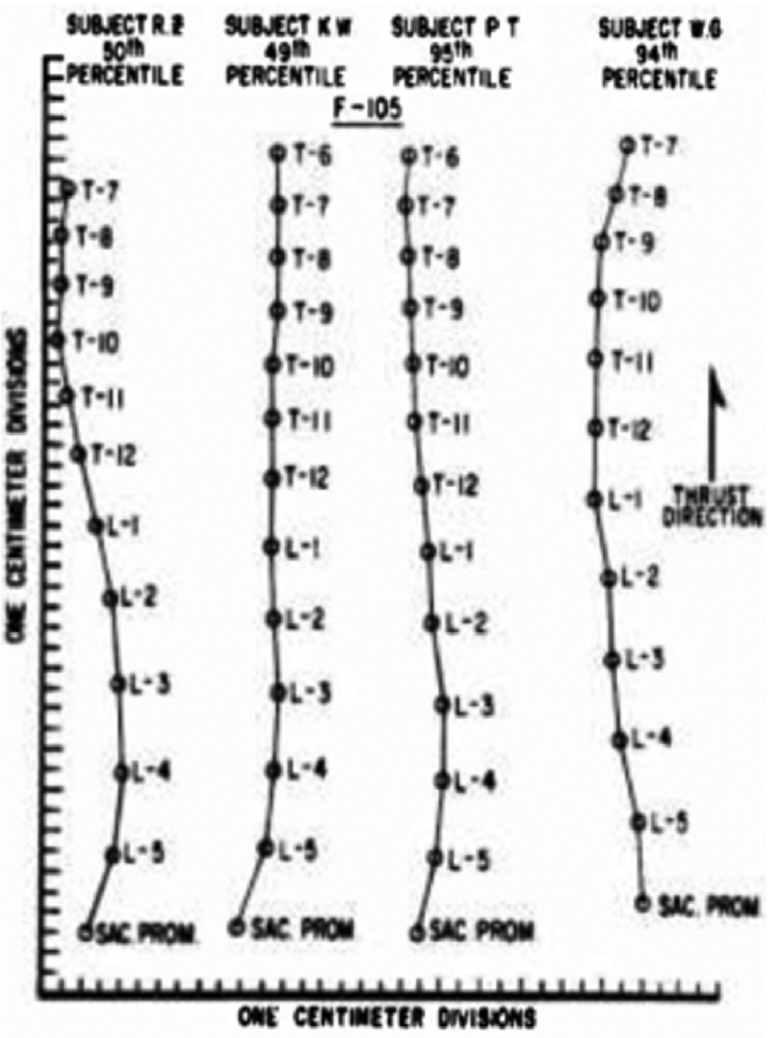

Fig. 1. Depiction of spinal alignment by Aerospace Medical Division, 1969 [4].

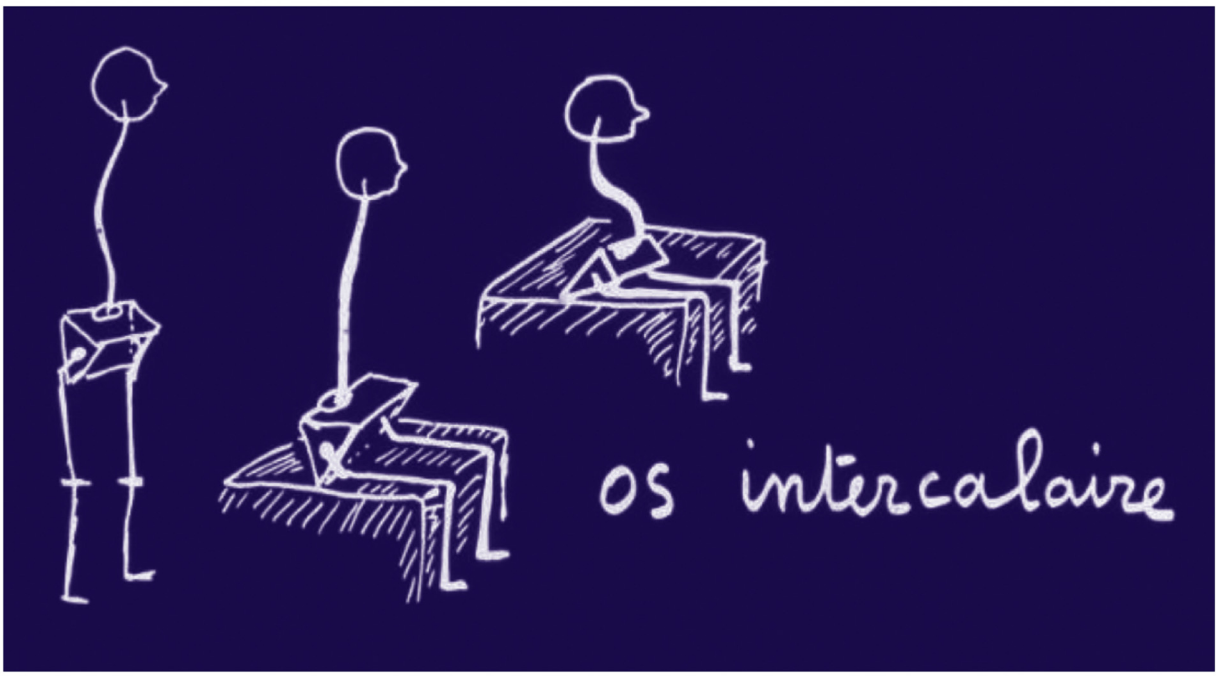

Fig. 2. Illustration of the pelvic vertebra illustrated by Jean Dubousset, 1972 [6].

Fig. 3. Illustration of the spine by da Vinci [12].

outcomes, there is a shortage of literature examining the history of spinal alignment. Prior literature instead has chosen to focus on a specific technique or a more generally history of spinal surgery [8–10]. This article aims to examine the historical development of spinal parameters and the impact this has had on surgical outcomes in addition to outlining the current areas of focus within the field.

Early efforts in spinal alignment

Interest in spinal malalignment goes back nearly 3500 BC to illustrations by the Ancient Greeks [11]. Credit for the first accurate anatomical illustrations of the spine, however, is given to da Vinci for his revolutionary sketches which correctly depicted the S-shape of the thoracic and lumbar regions of the spine for the first time (Fig. 3) [12]. Despite this early historical fascination with the spine, the field of spinal alignment would be confined to illustrations until the proposal of the first and arguably most well-known measure of spinal alignment in 1948 by John Robert Cobb as part of evaluating and managing scoliosis curves (Fig. 4) [11]. Known as the Cobb angle, the measurement is performed by drawing 1 line along upper endplate of the uppermost involved vertebrae and another line along the lower endplate of the lowermost involved vertebrae then drawing perpendiculars from each of these lines. This angle of

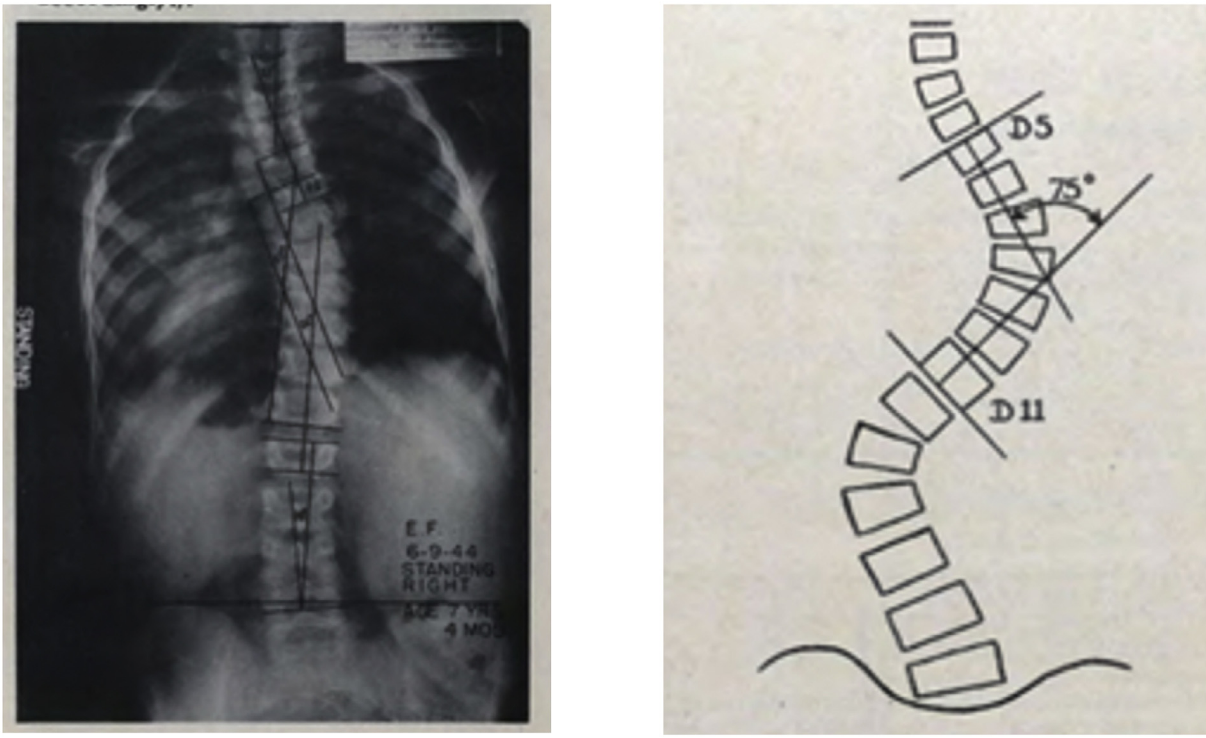

Fig. 4. X-ray and Illustration from Cobb's "Outline for the study of scoliosis" [11].

intersection is the Cobb angle and serves as the standard curvature estimation [13]. The Cobb angle was initially designed to measure curvature in the coronal plane but has since been adapted to measure regional curvature at the cervical, thoracic, and lordotic level. Other methods, such as the Harrison posterior tangent method, have been proposed to measure CL with greater accuracy; however, the Cobb angle remains the standard method of estimating regional curvature at all levels due to its simplicity and ease of use [14,15].

After the creation of the Cobb angle, the following research focused on determining a standard posture for evaluation as well as limits of normal versus excessive or insufficient spinal curvature. In 1982, Stagnara et al. used 100 young adults with no known pathology to determine normal references for kyphosis and lordosis. His method involved a lateral roentgenogram of the patient in a standing position followed by taking reciprocal angulation measures at the level of each vertebral body from S1 to T4 [16]. While this method seems laborious in comparison to standard evaluations, it was a massive step in determining what should be considered individual variation versus pathologic [16]. In 1985, During et al. made further progress in defining what could be considered normal alignment. In his study he analyzed the postural parameters of spondylolysis patients in comparison to healthy volunteers and found these parameters differed significantly between groups. Furthermore, he was also able to show correlation between the angle of the sacrum and lordosis in the lumbar spine [17]. While missing many of the terms used so frequently in current research, the methodology and attempt to define "normal" show glimpses of what was soon to come in the field of spinal alignment.

Defining measures of spinal alignment

It would be nearly 30 years after the development of the Cobb angle before the introduction of additional parameters to the field of spinal alignment. Before new parameters were introduced, Dubousset conceptualized the idea of spinal alignment with "conus of balance" to describe the body's goal of maintaining balanced, upright posture with minimal muscle action (Fig. 5) [18]. For example, in the case of loss of LL, there is an increase in spinal and lower limb compensation in order for the body to maintain a horizontal gaze and upright posture [6]. This theory in combination with Dubousset's classification of the pelvis as the final vertebra motivated much of the following work investigating the influence of the pelvis on spinal alignment, such as in the case of Duval-Beaupere's creation of 3 new spinopelvic parameters in 1992: pelvic incidence (PI), pelvic tilt (PT), and sacral slope (SS) [19].

Duval-Beaupere recognized there was a notable lack of anatomical criteria for normal posture with most studies offering only morphological descriptions. She acknowledged the contributions of both Stagnara and During as influential steps in creating anatomical criteria and as she hoped to build on these findings with his new spinopelvic parameters (Fig. 6). Duval-Beaupere described PI as a fixed anatomical parameter defined as the angle between a line drawn from the center of the femoral head axis to the midpoint of the sacral plate and the perpendicular to the sacral plate [6,19,21]. She defined SS as the angle between the sacral endplate of the S1 vertebra and the horizontal. PT is considered a dynamic parameter that changes with rotation of the pelvis and is defined as the angle between a line drawn from the center of the femoral head axis to the midpoint of the sacral plate and the vertical (Fig. 7) [6]. The relationship between these parameters is PI= PT+SS [19,22]. More recent work has determined normal ranges for each of these parameters in asymptomatic patients. In the case of PT, positive values refer to posterior rotation or retroversion of the pelvis whereas negative values refer to anterior rotation or anteversion [23].

The next parameters introduced were the T1 and T9 tilt by Legaye and Duval-Beaupere in 1993. Now most commonly referred to as the T1 or T9 spinopelvic inclinations (T1SPi, T9SPi), T1SPi is the angle between the vertical line and the line drawn from the center of the T1 vertebral body to the center of the bicoxofemoral axis whereas T9SPi is the angle between the vertical and the line drawn between the center of the T9 vertebral body and the center of the bicoxofemoral axis [24]. Shortly after the introduction of these parameters, Roger Jackson introduced the sagittal vertical axis (SVA) in 1994 as a simple way to assess global alignment. The parameter is the horizontal offset from a plumb line dropped from the C7 vertebral body to the postero-superior corner

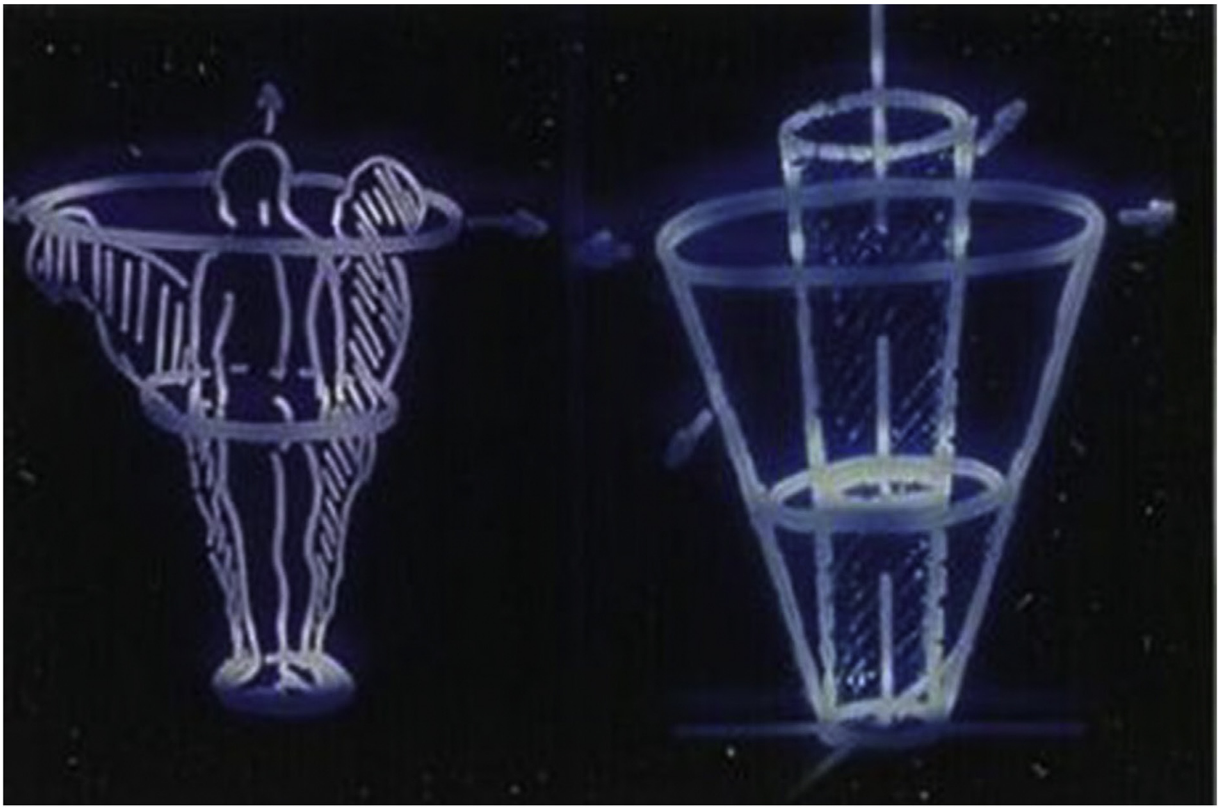

Fig. 5. “Conus of economy” illustrated by Jean Dubousset [20].

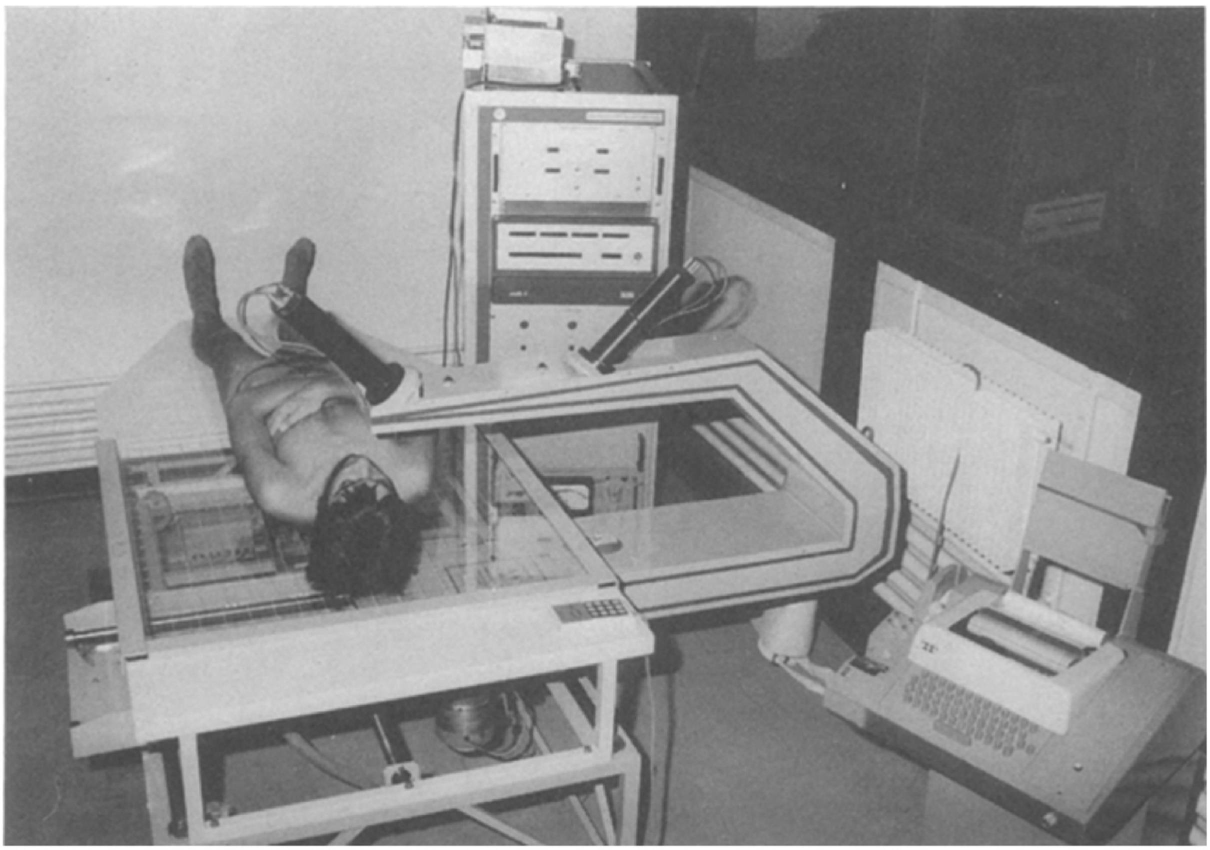

Fig. 6. Barycentremetre table used in Duval-Beaupere’s initial study [19].

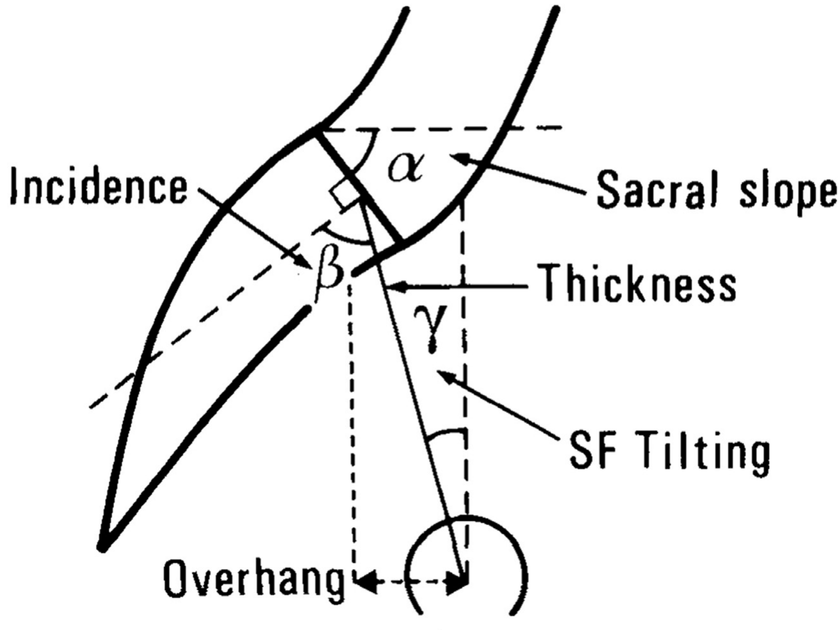

Fig. 7. Illustration of spinopelvic parameters from Duval-Beaupere's 1992 study [19].

of the sacral plate. SVA can be used to classify the patient as in neutral, positive, or negative alignment based on where the measure falls in relation to the normal range of −0.05cm +/− 2.5cm [25]. T1SPi is traditionally considered to correlate well with SVA; however, in 2009 Lafage et al. showed that T1SPi better correlates with Health Related Quality of Life (HRQOL) measures than SVA and advantageously avoids measurement errors seen in SVA in noncalibrated radiographs [26]. Despite its potential limitations, SVA is still used frequently in evaluations due to its ability to simply characterize general truncal alignment.

Modern measurements of alignment

More recently, the field of spinal alignment has had new parameters introduced: Spino-Sacral Angle (SSA) in 2006 and the T1 Pelvic Angle (TPA) in 2014. Prior research had reported that the radiographic location of the SVA may not mimic the position, and therefore the alignment, that a patient has during normal activity [27]. Feeling that evaluation of global alignment in a standard position still provided clinical value, Roussouly proposed the SSA as a more error resistant substitute for SVA. SSA is defined as the angle between a line from the center of C7 to the center of the sacral endplate and the sacral endplate itself [28]. The authors argue that SSA is a potentially more accurate measure of truncal alignment because it does not include the large variability seen in the horizontal distance between the C7 plumb line and the posterior edge of the sacral end as measured in SVA.

Hoping to simplify the evaluation of spinal deformity, Protopsaltis et al. introduced the T1 Pelvic Angle (TPA) as a way to combine SVA and PT to measure global spine deformity. TPA is the angle defined by a line from the femoral heads to the center of the T1 vertebral body and a line from the femoral heads to the center of the superior sacral endplate [29]. Another way to conceptualize the TPA is that it is the sum of T1SPi and PT [6]. Like Roussouly, Protopsaltis was concerned existing measures could be affected by positional variability including variation in standing compensation such as from knee flexion. The authors argued that because TPA includes both spinal inclination and PT, it should be less affected by these positional variations. In this initial study, increasing values of TPA correlated with significant and progressively worsening health status as measured by the Oswestry Disability Index [29]. Using the prior work of Vialle et al., the average value of TPA in asymptomatic patients was reported as 12° [30].

Alignment parameters and spinal mechanics

By the early 2000s, many of the most used measures of spinal alignment had been defined. From there, research shifted focus towards predictive modeling and equations using these parameters to better explain the biomechanics of the spine. Building off the early finding, PI=PT +SS, Vialle et al. proposed 2 predictive formulas to estimate theoretical PT and SS based on the fixed parameter PI. Vialle found that PT = 0.37*PI-7 and SS= 0.63*PI +7 [30]. These equations highlight that one can expect a greater variation in the sacral slope in comparison to the pelvic tilt. These equations also emphasize that with a greater PI, the SS is large therefore giving a patient a greater ability to compensate with pelvic retroversion in cases of malalignment [6,30].

Shortly after, pelvic incidence minus lumbar lordosis (PI-LL) was introduced. Part parameter part equation, PI-LL was meant to describe the relationship between the lumbar spine and the pelvic morphology and offer an estimate of the amount of lordosis required to restore alignment. The parameter was first introduced by Schwab et al. in 2010 [31]. Schwab referred to patients with PI-LL mismatch >9° and was able to show significant differences in ODI in patients with PI-LL mismatch versus patients without [31]. The parameter was proposed and written as PI-LL with a threshold of below or above 10° to ensure good alignment [31–33]. While this equation is extremely useful as a starting point, more recent research has shown that there is some deviation from this rule in specific cases. To provide a more exact formula to relate PI and LL, the equation LL = (PI+TL)/2 +10 was proposed by Schwab in 2014 in hopes of improving surgical planning [34].

As part of the initial 2010 investigation, Schwab also provided a general outline for the relationship of the well-known spinal parameters stating that in order for good alignment to occur, LL should be proportional to PI while TK is also proportional to LL [31]. Building on these findings, in 2016 Le Huec et al. reported that the theoretical relationship is T1T12 kyphosis = 0.75 * L1S1 lordosis [35,36]. Le Huec further described the theoretical relationship between LL and PI as L1S1= 0.54PI +27.6 providing evidence for Schwab's claim that PI and LL should be proportional. Le Huec also gave the equations PT=0.44*PI-11.4 and SS= 0.54PI + 11.9 to more exactly define the influence of PI on PT and SS [35].

One of the most recent findings in the field of spinal alignment and biomechanics is that lumbar lordosis is not evenly distributed throughout the lumbar spine [37,38]. As alignment research started focusing on the shape and apex of the lumbar curvature, a 2018 study estimated that on average approximately 62% of LL is achieved from L4-S1 whereas only 38% is achieved from L1-L3. While some variations exist in L4-S1 lordosis per pelvic incidence, the proximal segments are more involved to increase lordosis with proximal lordosis accounting for up to 50% of total lordosis for patients with high PI. With the recent introduction of new predictive equations, surgeons theoretically now had a greater capability to plan their surgeries to achieve the ideal alignment thresholds based on the unique anatomy of a patient.

Clinical relevance of spinal alignment

The value of these parameters was well established from a research perspective, with a variety of articles published looking at spinal alignment with the defined parameters and more recently described equations. The clinical use of these parameters rested upon research next being able to show correlation between HQROL measures and abnormal values for spinal alignment parameters. In 2002, Schwab et al. [39] were some of the first researchers to establish the clinical significance of these parameters by showing that a loss of lumbar lordosis, increased thoracic kyphosis, lateral vertebral olisthy, and L3 and L4 endplate obliquity angles correlated with poorer outcomes on the visual analogue scale (VAS). Glassman et al. built on these initial findings in 2005 by showing that positive sagittal balance as measured with SVA was the most reliable predictor of clinical symptoms in cases of adult spinal deformity regardless of fusion status [40].

One of the most important initial findings was that the coronal Cobb angle, a common measure of spinal deformity, did not have significant correlation with HRQOL measures and that coronal deformity did not impact pain and disability as much as sagittal measures, with. LL, T1SPi, SVA, PT, and T9SPi all shown to be highly correlated with HRQOL measures [26]. In addition to demonstrating the clinical value of these parameters, this study gave support to Dubousset's initial emphasis on the importance of the pelvis by correlating PT with clinical presentation. Schwab emphasized the importance of PT by demonstrating that an increase beyond the threshold of 20° of PT correlated with limiting walking ability and a lower reported quality of life [31]. Schwab's 2013 study supported the importance of PT by showing that evaluation of ASD using PT, PI-LL, and SVA allowed for accurate prediction of patient disability and could potentially guide therapeutic management. They also provided threshold values for severe disability as marked by ODI>40 which include PT greater than 22°, PI-LL of 11° or more, and SVA of 47 mm or more [33].

In the process of establishing clinical significance for a wide variety of parameters, a simultaneous interest in creating a classification system that could combine these parameters and predict clinical outcomes for complex curves started to develop. The earliest attempt at classification was introduced in France in 2003 and published in English in 2005 by Roussouly et al. in which lumbar lordosis was classified into 4 types based on sacral slope, pelvic tilt, and position and shape of the pelvis [41]. The system also considered the apex of LL, arc of lordosis, inflexion point, and the general distribution of lordosis in the spine (Fig. 8). Roussouly believed his system would be useful in recognizing the immense variation in spinal alignment and how patterns of variation may lead to the development of degenerative disease [42].

In 2006, Schwab proposed one of the first classification systems for adult spinal deformity based on the clinical impact of various changes throughout the spine. The system included 3 parameters: apical level, lordosis modifier, and subluxation modifier. Five types of apical levels were described based on the location of the major curve and any additional minor curves. There were 3 categories of lordosis modifiers ranging from marked to no lordosis. Similarly, subluxation had 3 categories, ranging from no subluxation to subluxation greater than 7 mm [43]. Schwab applied his classification system to 947 patients and was able to show statistically significant differences in disability scores across apical groups and was able to show that the application of modifiers, such as loss of lumbar lordosis, within groups also demonstrated statistically significant differences in disability and ODI scores [43].

In 2013, Schwab proposed an updated version of his classification system called Scoliosis Research Society (SRS)-Schwab classification system. Changes to his system were based on updated research that emphasized the fundamental role of the pelvis in spinal alignment and a belief that spinopelvic parameters were therefore an essential part of classifying deformity [26,32]. In this system, 4 coronal curve types were described and 3 sagittal modifiers: PI-LL, global alignment based on SVA, and pelvic tilt. Each sagittal modifier was classified into 3 types based on the severity of the deviation. The clinical usefulness of this study was later supported by a 2013 study which emphasized both the value of exact language to describe and classify presentations of ASD and showed that classifications based on the SRS-Schwab system reflected the severity of symptoms using HRQOL measures [44].

Building on the SRS-Schwab system, Yilgor et al. proposed the Global Alignment and Proportion (GAP) Score in 2017. Because PI is a continuum, the authors argued that no categorization system could define normal pelvic alignment for all PI values, so a scoring system may be more useful to determine normal versus abnormal alignment based on PI. The GAP score includes relative pelvic version, relative lumbar lordosis, lordosis distribution index, relative spinopelvic alignment, and an age factor to calculate a total score from 0 to 13 that can then be used to categorize patients as proportioned, moderately disproportioned, or severely disproportioned [45]. In the initial validation study, researchers showed that GAP scores were helpful in understanding the risk of mechanical complications [45]. However, data on generalizability and external validation of the GAP score remains conflicted. Jacobs et al. reported that the GAP score was effective in predicting mechanical complications and was actually a more appropriate tool than the SRS-Schwab classification [46]. In contrast, Kwan et al. reported that GAP scores were not correlated with increased risk of mechanical complications or revisions [47]. Hiyama et al. similarly reported that GAP scores did not vary significantly between patients that suffered from proximal junction failure or rod breakage patients that did not [48]. The mixed results suggest further research to determine a modified GAP score that accounts for additional risk factors may be necessary.

Parameters and surgical outcomes

Beyond patient reported outcomes, sagittal alignment of the spine was extremely groundbreaking in better understanding and preventing mechanical complications associated with spinal reconstruction with fusion constructs in both degenerative and spinal deformity settings. Barone et al. reported that patients with mechanical complications were more likely to have a lower LL and a higher PT and PI-LL relative to patients that did not experience mechanical complications [49]. Elshamly et al. similarly reported that high PT, PI-LL mismatch, and PI are associated with increased risk of rod breakage following thoracolumbar fusion [50]. While low LL is associated with mechanical complications, overcorrection of LL postoperatively beyond age-specific values has also been shown to increase a patient's risk of developing proximal junctional kyphosis [51]. Elevated mechanical complication rates for under and overcorrection of LL emphasizes the extreme importance of precision and patient specific correction in restoring alignment.

In degenerative spine, failure to restore normal values of alignment parameters has been correlated with poor surgical outcomes. In both 2015 and 2017, PI-LL mismatch greater than 10° following lumbar fusion was shown to significantly increase the likelihood of developing adjacent segment disease and undergoing revision surgery [52–54]. The estimated risk of requiring revision surgery was reported as 10 times greater in patients with PI-LL mismatch and every 1° of postoperative mismatch was estimated to increase the odds of requiring revision surgery by 1.4 fold [53,54]. Building on earlier findings regarding the distribution of lumbar lordosis, a recent publication showed that a re-

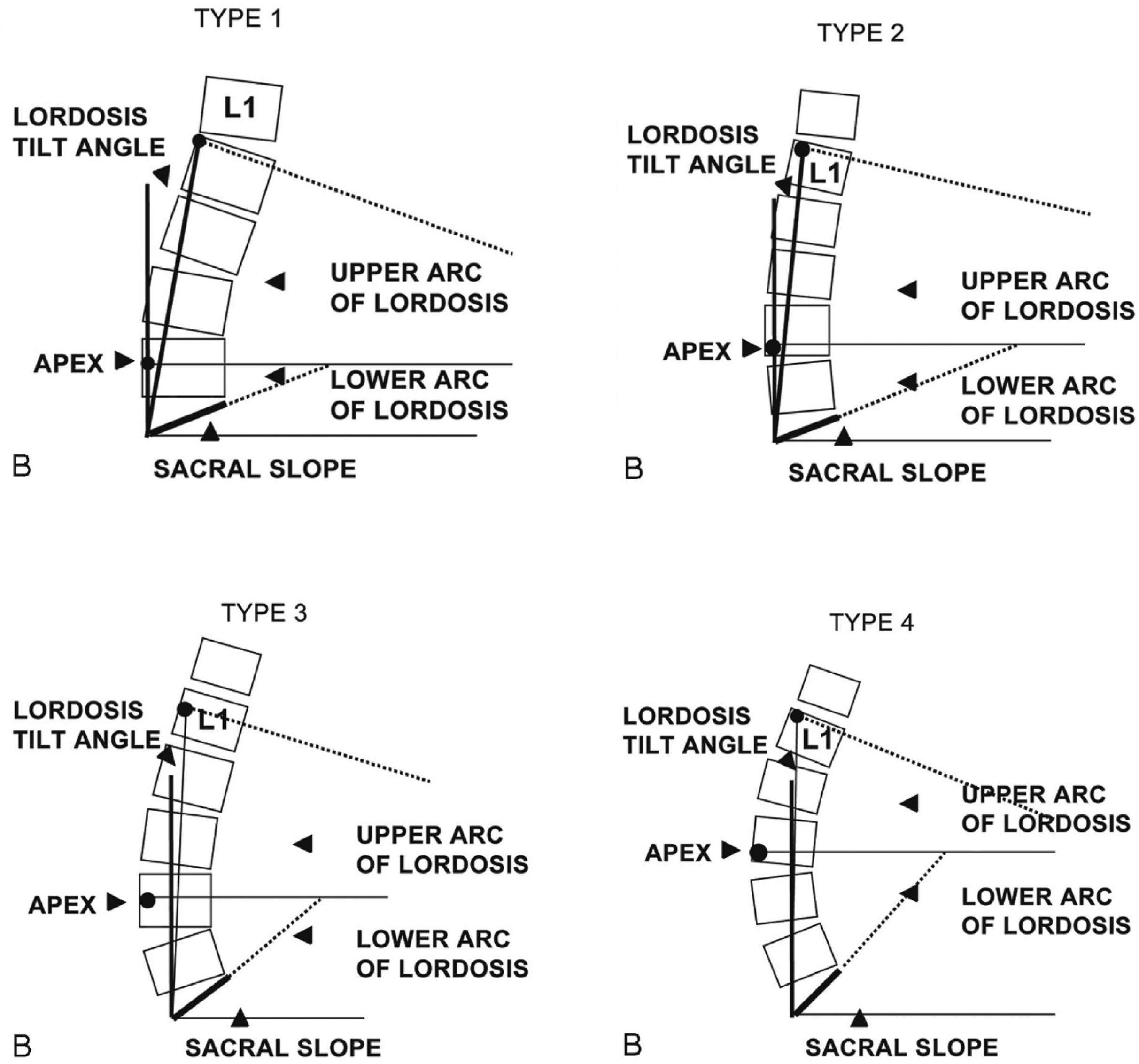

Fig. 8. Illustration of Roussouly classification from original paper [42].

PI Category	T10-L2	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1
40	-6.9	1.7	4.4	9.5	15	17.5
50	-4.3	1.7	6.2	10.1	15	20
60	-4.3	3.1	7.9	11.2	15	20
70	2.1	4.9	9.2	15.4	15	20
80	2.1	5.5	11.9	17	19	20
90	2.1	7.3	14.6	12.9	22	20

Fig. 9. Segmental alignment by PI [56].

duction in distal lordosis following fusion surgery leads to compensatory increases in lordosis at adjacent levels and ultimately predisposes patients to reoperation for adjacent segment disease [55].

Researchers have also looked at PI adjusted segmental specific contributions to lordosis in the corrective surgeries for degenerative spine and ASD (Fig. 9) [56–58]. In 2024, Diebo et al. found that restoring segmental lordosis values to normative PI adjusted values leads to improved surgical outcomes in comparison to under or overcorrection. This study also showed that overcorrection of proximal lordosis at the thoracolumbar junction led to higher rates of proximal junctional kyphosis and under correction of distal lordosis as the thoracolumbar junction led to higher rates of implant failure [56]. By using segment specific contributions to lordosis, surgeons may be better able to take a personalized and exact approach to realignment based on the patient's pelvic morphology [57].

Looking beyond the spine

Since the introduction of the cone of economy, the idea of spinal and lower extremity compensation has been well accepted in the research community. Initially, compensation referred mostly to changes in segmental curvature or pelvic parameters in response to degenerative or age-related changes. Researchers recently have started to recognize that the idea of compensation extends far beyond the spine into the hips and

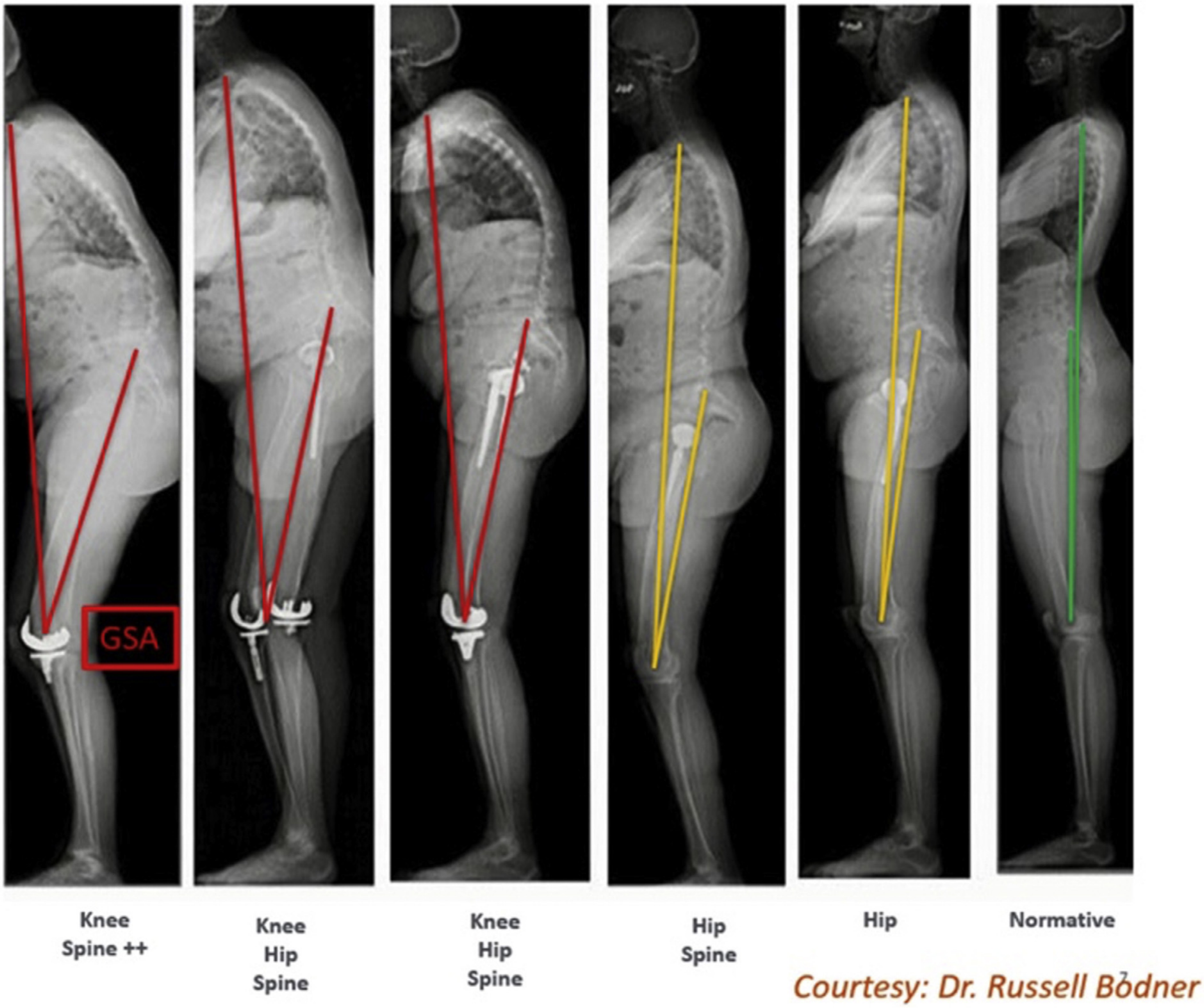

Fig. 10. Visual demonstration of the relationship between hip, knee, and spine pathology [68].

often the lower extremities. Pelvic shift (P.Sh) was one of the first new parameters introduced in order to measure the amount of compensation in cases of adult spinal deformity. P.Sh is defined as the magnitude of the offset between the S1 posterior superior corner of the plumb line and anterior cortex of the distal tibia [6]. Several studies have shown that an increase in SVA leads to an increase in posterior pelvic shift as one of the earliest mechanisms of compensation [59,60]. P.Sh has also been shown to correlate with ODI, suggesting it is a good indicator for the severity of deformity and amount of compensation being recruited [61].

As early as 2008, Lafage advocated in favor of including the lower extremities in evaluation of spinal deformity. This early study found that with an increase in SVA, a posterior shift of the pelvis occurs which requires a change in hip flexion and extension and that both the knee and ankle joints are likely involved in maintaining a patient's gravity line as this shift occurs [60]. Knee flexion is evaluated using the knee flexion angle (KA) which is the angle between the mechanical axis of the femur and the mechanical axis of the tibia. Ankle dorsiflexion (AA) is measured as the angle between a line drawn perpendicular to the talus and a line drawn through the mechanical axis of the tibia. Lafage's proposal regarding the importance of knee flexion was later supported by a 2011 article which demonstrated that knee flexion was well correlated with a lack of lumbar lordosis and a 2016 article that showed knee flexion is correlated with ODI in ASD [61,62].

Following these early findings, research focused on establishing the order of compensation. It is generally agreed that hyperextension of the adjacent vertebral segments occurs first followed by maximum hip extension and pelvic tilt before finally recruiting knee flexion and ankle dorsiflexion [62–64]. More recent studies, however, have called this chain into question and shown that compensation may vary from patient to patient and knee flexion could play a greater role earlier in maintaining upright position [64]. The relative contributions of the lower extremities to pelvic retroversion as part of compensation was determined in 2023 with 61% of PT coming from knee flexion and 39% coming from hip extension for a given PI [63]. This finding emphasizes the importance of the knees to spinal alignment and raises questions about the consequences of degenerative changes in the hips and knees on a patient's ability to compensate.

Degenerative changes in the lower extremities have been therefore a topic of interest in spinal alignment literature. Severe hip osteoarthritis (OA) in patients with ASD was found to result in compensation through P.Sh instead of hip extension [65]. Balmaceno-Criss et al. recently showed that for the same degree of spinal deformity, more severe hip OA was associated with worse truncal and full body alignment with posterior translation of the pelvis (Fig. 10). This study also showed that patients with severe hip and knee OA had decreased hip extension and PT but increased knee flexion [66]. Diebo et al. was further able to show that hip OA has a persisting impact on patients with ASD even after corrective surgery. In their study, patients with ASD who had severe hip OA had worse SVA measurement and PROMs at baseline, and this difference persisted at 1 year following corrective spinal surgery [67]. The results of this study highlight the importance of considering the lower extremities and their relationship with the spine when managing ASD. Given these preliminary findings and an increasingly aged population with multiple degenerative conditions, research on the relationship between spinal alignment parameters, compensation, and osteoarthritis and arthroplasty will likely be a continued area of interest for years to come.

Conclusion

The field of spinal alignment has grown immensely since the creation of its first parameter, the Cobb angle, in 1948. The introduction of full spine x-rays propelled the field forward and encouraged researchers to consider the importance of the pelvis in maintaining spinal alignment. From there, a plethora of new parameters were introduced to help spine providers quantify spinal alignment. Using these parameters, researchers developed predictive formulas that could describe both the distribution of curvature throughout the spine and the relationship between these newly defined parameters pre and postoperatively. Those sagittal parameters were found to be clinically relevant with correlations to HRQOL and surgical outcomes. Fully body sagittal analysis is recommended when possible as compensation beyond the spine has become an area of growing interest. The role of the hips, knees, and ankles in maintaining upright position was established in severe cases and databases of ASD. Degenerative joint conditions and arthroplasty in patients with ASD complicate a patient's ability to compensate in ways that are just starting to be identified. Given this new area of growing interest, the future of spinal alignment research is bright.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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